Proceedings of the 2005 Winter Simulation Conference
M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, eds.

ONTOLOGIES FOR SUPPLY CHAIN SIMULATION MODELING

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ABSTRACT

Simulation might be an effective decision support tool in supply chain management. The review of supply chain simulation modeling methodologies revealed some issues one of which is the practicability of simulation in the supply chain environment. The supply chain environment is dynamic, information intensive, geographically dispersed, and heterogeneous. In order to develop usable supply chain simulation models, the models should be feasibly applicable in the supply chain environment. Distributed simulation models have been used by several researchers, however, their complexity and usability hindered their continuation. In this paper, a new approach is proposed. The approach is based on Ontologies to integrate several supply chain views and models, which captures the required distributed knowledge to build simulation models. The Ontology core is based on the SCOR model as the widely shared supply chain concepts. The ontology can define any supply chain and help the user to build the required simulation models.

1 INTRODUCTION

Enterprises focus on their core competencies and outsource the out-of-core "need" to other enterprises that have this "need" as their core-competency. These enterprises digitally integrate to collaborate and stimulate operation as one unit through real-time communication and information sharing in the form of a supply chain. The main goal of any supply chain is to direct the collection of the core-competencies towards a predefined goal or market opportunity. Supply chain management (SCM) is managing group(s) of independent business units and enterprises to temporarily work/partner together as one unit to plan, design, produce, and deliver a product/service to satisfy an immediate or projected market demand at the highest possible performance level.

SCM decisions are classified into strategic decisions, tactical decisions, operational decisions, and real time decisions. In some cases, making these decisions requires modeling the supply chain. Supply chain modeling is very challenging because the model is an abstraction of the real system which models a particular view. Also, each model has its own objectives, scope, level of details, and assumptions. In the supply chain there are diverse views that can be modeled which requires an intelligent modeling methodology to capture these views. We were purely concerned with discrete-event simulation modeling as one of the most effective decision support tools for supply chain managers and analysts. In particular, we focused on supply chain simulation modeling methodology for supply chain management. The analysis of supply chain simulation modeling methodology revealed some problems and issues that might be resolved. Our research aims to resolve these problems/issues through developing a generic ontology that will be used as a centralized, yet distributed, knowledge capturing mechanism. The ontology will enable the user to capture the necessary knowledge to build and generate simulation models.

1.1 Supply Chain Simulation Problems and Issues

There are three supply chain simulation modeling problems/issues identified. First, Supply chains are never static; in fact they are highly dynamic. Simulation modeling is used to model and analyze supply chains to support decision making that entails the dynamics and the stochastic nature of the supply chain. If the knowledge and information used to build and run simulation models is not synchronized with the supply chain dynamics, e.g. model structure is static or outdated, then the benefits of using simulation modeling will vanish and the output of the models will be invalid. Thus, yielding to biased or inaccurate decisions. Therefore, there is a need to capture or update this knowledge and information in real time from the supply chain network prior to running the simulation model. Second, supply chains are large and complex (space and time). Consequently, simulation models of supply chains become large scale complex models, as well as requiring large amounts of knowledge and information for modeling. The simulation modeling life cycle begins from the of the conceptual model of the real supply chain, through development of the simulation model, through populating the model with the required data and information, modeled in an appropriate format, and ends with running the simulation experiments. Supply chain simulation modeling has a long cycle time for complex models, this affects the model development time and the applicability of simulation in solving supply chain problems at any decision level. Therefore, there is a need to decrease the modeling cycle time to make simulation a responsive and applicable tool for supply chain decision making. Third, enterprises invested enormously in supply chain information technology to replace physical inventory with information/data. The information technologies adopted vary in scale, usage, and level of technology. These systems include databases, information systems, Enterprise Resource Planning (ERP), Advanced Planning and Scheduling (APS), Supply Chain Management (SCM), or any other legacy system. In fact, most of the supply chain data resides in part or in full in these systems. In a supply chain these systems are heterogeneous and geographically dispersed over the supply chain network. From a simulation perspective, the data and information required to populate the supply chain simulation models resides in these heterogeneous-dispersed systems. Therefore, there is a need to identify existing enterprise application systems in a particular supply chain, a method to remotely access these systems, identify the information required for the simulation model under consideration, determine which system(s) these information resides in (and in which format), identify the data schema of these systems, and extract the information required.

1.2 Potential Resolutions of the Issues

The analysis of the problems and the issues revealed the needs that might position simulation modeling a better decision support system for supply chain management. These needs might be achieved through the following:
First, It is believed that an adequate step is to comprehensively define the supply chain, the supply chain can be comprehensively defined at four different levels. These levels are the supply chain level, the enterprise level, the enterprises' elements level, and the interaction level. At the supply chain level, the various enterprises are defined, e.g. suppliers, customers, suppliers' suppliers. At the enterprise level, the enterprise elements are defined, e.g. processes, functional units, software systems. At the enterprises' elements level, each element in the enterprise is explicitly defined, e.g. process decomposition, software system information content, functional unit processes. At the interaction level, the flows and interdependence between the elements are defined, e.g. supplier 1 process A has information output X that is an input to warehouse 1 process B. Second, develop a supply chain ontology that explicitly captures the definition of the supply chain and easily shared within/across the supply chain. Third, enrich the ontology with simulation specific knowledge that will aid in building simulation models.

These three potential resolutions can be developed within an Ontology for supply chain management simulation. Our hypothesis is that the combination of Ontology, business process modeling, the SCOR-model, and the semantic web will result in an effective ontology for supply chain simulation modeling. This combination was never studied before. The system aims to make supply chain modeling highly automated, proactive, and responsive. The supply chain ontology will contains the methods and techniques to handle the following:

1. Identify the knowledge, information, and data required for a specific supply chain model.
2. Populate the ontology with the required knowledge.
3. Build simulation models from the knowledge captured in the ontology.
4. Extract the data and information required to run the simulation model.
5. Develop the necessary input models.
6. Design the simulation experiments.
7. Run the simulation experiments.

1.3 Paper Outline

In this paper, some background information on supply chain management, supply chain Operations Reference-model (SCOR-model), and semantic web are described in section 2. supply chain modeling is discussed in section 3 research approach and the ontology will be discussed in section 4. Finally, the conclusion of the work and the future work will be discussed in section 5.

2 BACKGROUND

This section will provide background information on the individual approaches that have been combined to develop the ontology. The framework might solve the problems and resolve the issues of supply chain simulation modeling.

2.1 Supply Chain Management

The first SCM wake-up call was after the oil shock in 1973, where inventory holding and moving cost increased significantly, demand declined, order quantity decreased, order frequency increased. Enterprises envisioned that replacing the physical inventory with information would dampen the shock and would enhance their performance. Therefore, the ultimate performance of the supply chain would depend on the extent to which it effectively manages and integrates the entire supply chain knowledge and information.

Knowledge and information in any supply chain is originated and owned by different supply chain partners. These pieces of information are dispersed over the supply chain network in different systems, format, level of details, etc. Any decision making, modeling, or performance assessment requires specific knowledge or information to be available collectively for a specific application (e.g. simulation modeling). Due to several factors (e.g. technology, interoperability, trust, sharing modes, etc.), sharing and collecting this knowledge and information became a supply chain important and challenging issue, sometimes a barrier. (Motwani, Madan, & Gunasekaran 2000; Prasad & Tata 2000; Swaminathan, Sadeh, & Smith 1997; Thonemann 2002; Yu, Yan, & Cheng 2001; Zhao, Xie, & Zhang 2002) demonstrated that sharing the right information in the right time is important for better decision making. It is also significant for accurate and valid supply chain simulation models. The automation of sharing and collecting supply chain knowledge and information is considered as an "unresolved" issue.

Over the past several decades, enterprises have invested in automating their internal processes. While this investment has yielded significant improvements in efficiency, this efficiency has been limited to internal processes and created islands of automation, which are isolated from the rest of the supply chain. In general, these investments did not pay back in many cases. Enterprises faced the fact that a lot of information technology-related problems still exist, which affects supply chain simulation modeling. These problems are:

- Knowledge and information overload
- Information technologies adopted (e.g. ERP) might not be efficient or flexible enough for the dynamic nature of the supply chain.
- Insufficient information sharing between supply chain partners, enterprise application systems, and decision making tools specially simulation.
- Poor responsiveness and slow decision making
- Poor real-time visibility of information dispersed over the supply chain

(Huang, Lau, & Mak. 2003) categorized supply chain knowledge and information into six categories:

1. *Product:* product information includes product design, product structure, product cost, material information, inspection data, durability (important for perishable products), support and maintenance information, etc. This information varies by product but generally it describes the physical, functional, and storage characteristics of a product.
2. *Process:* process information includes lead time, setup cost and time, process cost, policy, and quality. The time information is usually presented in average and standard deviation.
3. *Resource:* resource information includes capacity of resources.
4. *Inventory:* inventory information includes inventory level, holding and backlog cost, and control policy.
5. *Order:* ordering information includes the basic information in any supply chain. It includes demand or order quantity, due dates, and batch size.
6. *Planning:* planning information includes demand forecast, forecasting method, order schedule.

This categorization was focusing on the impacts of sharing production information and doesn't include all the supply chain knowledge and information necessary to construct and run simulation models. The literature falls short in defining supply chain knowledge and information, their characteristics and their interdependence.

2.2 The SCOR Model

The Supply Chain Operations Reference model (SCOR-model) was developed by the SCC (SCC, 2003) in 1996. The SCOR-model is a reference business process model that captures the widest view of supply chains, and can describe any supply chain to any level of details. The SCC is continuously updating the SCOR-model, which is now in its seventh version, in order to apply to the changing environment and advancement in the research, development, and technology associated with supply chain practices.

The SCC developed SCOR to be an industry independent, top-down model. The SCOR model is based on three different methodologies, including business process reengineering (BPR), benchmarking, and analysis of best practices. However, since the prime was the BPR, it makes SCOR a process centric model. The processes in the SCOR model are the processes that are found in any supply chain. The processes are defined generically to capture any supply chain of any type. The analysis of the SCOR model revealed that the model contains the following:

- Definition of the supply chain processes
- Standard descriptions of supply chain processes
- The relationships between the processes
- Standard performance metrics of the processes
- Best practices that produce best-in-class supply chain performance

The SCOR model is structured around these five supply chain processes: Plan, Source, Make, Deliver, and Return. The five SCOR management processes are decomposable into three levels of details (SCC, 2003). The SCOR model is an ad hoc BPR model, as evident by its structure that does not follow any of the standardized or well structured business process modeling techniques such as the IDEF family or UML business modeling extensions. Moreover, the SCOR model does not provide an explicit view of the process flow, material flow, or information flow. In fact, these flows are either missing or implicit in the model processes; a separation of the flows will convey a better understanding and definition of the supply chain to fit the purpose of developing supply chain simulation models.

2.3 Semantic Web

Knowledge and Information sharing between supply chain partners was very slow and inefficient in the 60s, when supply chain partners shared information through mail, telephone, and fax. It remained slow and inefficient till the early 70s, when a number of businesses used the Electronic Data Interchange (EDI) to exchange invoices and purchase orders. Businesses that used EDI in their trade operations recognized the economic advantages of a fast, efficient and accurate information sharing. As the Internet evolved, the business world started to look at it from the supply chain perspective. The internet is a free-global network, which will be an effective replacement for the expensive EDI through its more economical solutions (Cagliano, Caniato, & Spina 2003; Fu *et al.* 1999). The growth of the Internet and the online population demanded an extension for the World Wide Web. According to (Berners-Lee 1998), the Semantic Web is an efficient extension of the World Wide Web. It is a web of interdependent and linked data and information; that can be easily interpreted and processed by humans as well as computers, as easy as running a query on a database. The development of a language to describe data and to be suitable for the semantic web began in 1996. In 1998, The World Wide Web Consortium (W3C)(W3C 2003b) formally approved a standard definition for the eXtensible Markup Language (XML). XML complements HTML. Whereas, HTML is used for formatting and displaying data, XML represents the contextual meaning of the data. Information formatted in XML can be exchanged across platforms, languages, and applications, and can be used with a wide range of development tools and utilities. There are two main XML-based standards for the Semantic Web, Resource Description Framework (RDF) (W3C 2003a) and Ontologies. RDF represents a data model or metadata, i.e., a common framework for expressing information that can be shared across applications. RDF can manage non-XML data as well as XML data, structured data, and semi structured data. RDF Schema provides information about the interpretation of the statements given in an RDF data model. The RDF framework is built on three pillars Object Attribute, and value. Ontology is a description of the concepts, relationships, set of terms, and languages of a specific domain. Ontology models all the entities and relationships in a domain. It captures the attributes of an entity and inheritance relationships as in object-oriented programming, and it also captures associations such as cardinality in relational databases. Ontologies enable communication between computer systems in a way that is independent of the individual system technologies, information architectures and application domain.

3 SUPPLY CHAIN MODELING

Modeling the supply chain requires generating different supply chain views. This is not a straightforward task; in fact, it is extremely complicated. Also, the generation of the different views were restricted by the available models and modeling techniques. There are two modeling suites which are the Integrated DEFinition (IDEF) family (KBSI, 2003) and Unified Modeling Language (UML) family (OMG, 2003). The review of both suites concluded that both suites will offer similar modeling capabilities. The suites will provide process flow models, material and objects state transition models, and information and information flow models. In order to generate supply chain models that provides the capability to capture the required knowledge to generate supply chain simulation models, IDEF3 Process flow description and IDEF3 Object state transition has been used.

The IDEF3 process flow description was used to generate the supply chain process flow view. The process flow view captured the supply chain processes and the logic sequence of these processes. The processes used to generate this view are the processes defined in the SCOR model three levels of details. However, new processes have been added and integrated with the SCOR model processes that were deemed necessary for the comprehensive definition.

IDEF3 state transition model was used to capture and generate the materials flow and transition in the supply chain in conjunction with the processes. The IDEF3 material state transition has been developed for three levels of details corresponding to the IDEF3 process flow three levels of details. In a simple context, the material state transition shows the state of the material before and after the process.

Other modeling techniques that was used to develop the other views are the supply chain network diagram, geographical maps, the thread diagram, cross-functional diagram, product structure, and objects structure. Finally, interdependence models using the Design Structure Matrix

(DSM) which has been used successfully in information intensive projects (Fayez et al., 2003).

4 SUPPLY CHAIN ONTOLOGY

The supply chain Ontology will provide the capability to integrate the SCOR model and the different supply chain views in a coherent representation. The Ontology is constructed to enable the user to extract a specific supply chain view or knowledge, such as simulation modeling view. It also provides the capability to extract a specific supply chain knowledge that spans over different views, such as the information required for a specific supply chain process. Finally, supply chain Ontology will enable the reusability of specific concepts in a restricted way, such as reusing the supply chain Ontology or part of it for a specific/new supply chain.

It has been considered that in order to build supply chain Ontology in such a way to be sustainable and successfully deployed in the supply chain community; it has to be constructed based on the current commonly shared knowledge. This is one of the lessons learned from the Ontology literature, in particular, previous Ontology projects. The approach that was used started by identifying the shared and broadly accepted concepts and knowledge in the supply chain, then formalizing these concepts and knowledge by coding the ontology using a standardized widely accepted Ontology language.

The only shared and broadly accepted concept and knowledge within the supply chain community is the SCOR model. Thus, it was used as the core for the supply chain Ontology. Another layer of the Ontology was built over the core Ontology to include all the supply chain views developed. This layer is called the middle Ontology, which explicitly and formally define all the concepts extracted from the different supply chain views and the comprehensive definition methodology of the supply chain. In fact, the supply chain core and middle Ontologies are generic. However, in order to enable the supply chain Ontology to be used in the supply chain dynamic environment by specific users for specific supply chains, another layer of the Ontology was constructed. This layer is called the Dynamic Ontology. The dynamic Ontology is used to define in an automated way a specific supply chain, supply chain partners, and their specifics by extending or constraining the core and the middle Ontology. The last step in the ontology development effort was to integrate the three ontological layers in a coherent unified Ontology and to encode it in a standard ontology language that can be used by any user in the supply chain community today. The Ontologies was developed using Protégé software. Protégé is a free open-source software tool that was developed at Stanford University for building Ontologies and knowledge based systems. Protégé was used to merge the three layers of the ontology and to code the ontology into OWL which is the current semantic web and W3C standard.

The ontology was built by defining classes, subclasses, properties, and instances that represents the supply chain level, the Enterprise level, the elements level (Processes and Materials), and the interaction level. The supply chain Ontology classes and Sub-classes are shown in Figure 1 and 2 respectively.

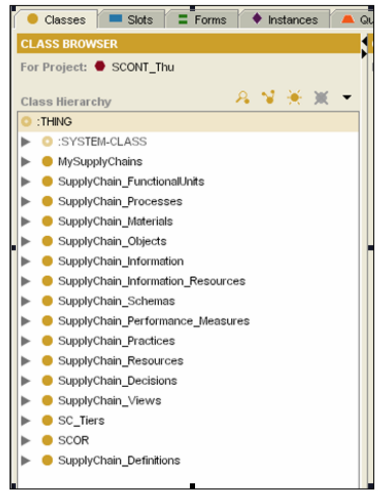

Figure 1: Supply Chain Ontology Classes

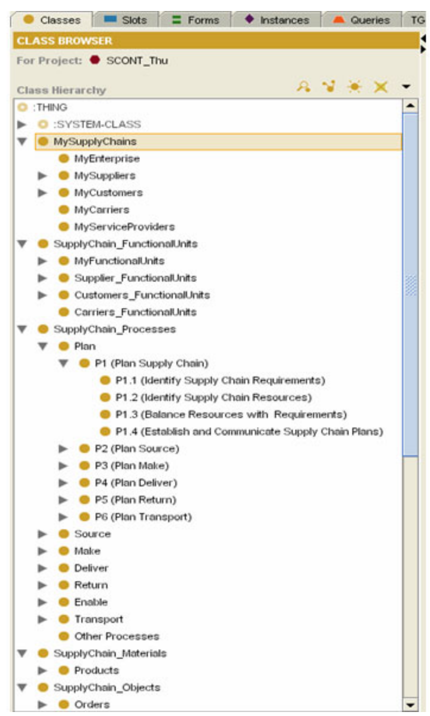

Figure 2: Supply Chain Ontology Sub-Classes

For the supply chain level, a class called "My Supply Chains" was defined where this class includes all the properties required to define the supply chain at this level.

At the element level, classes representing each element were defined. The classes include materials class, objects class, processes class, information resources class, etc. where each of these classes has their own sub-classes, properties, and instances. The properties of the elements classes are corresponding to the questions that realized the map which were the questions that the different supply chain views provided at the element level. For example, the process class has a property called has_name, where each sub-class and sub-sub-class inherited this property. Each process ontological instance will contain a value for the has_name property, e.g. Make.
The ontology is a process centric ontology. For this reason, all the middle ontology concepts were constructed relative to the processes. However, since the processes are at the element level, the integration was done with the concepts at the element level. For example, the material flow was encoded in the middle ontology with respect to each process, by identifying the material state before and after the process. If a process did not change the material state, the material before and after the process will be the same. A snapshot of the process element template is shown in Figure 3. The templates can be easily distributed across the supply chain to the supply chain partners. Each partner will populate the ontology with their specifics. The populated ontology provides the knowledge and information that will enable building supply chain simulation models.

5 CONCLUSIONS

In this paper, we developed a supply chain simulation ontology that integrated the necessary supply chain views. However, generating different supply chain views was not an easy task. It required tremendous efforts, research, and thoughts to select the modeling technique that will develop an accurate view. The generation of the views was also limited by the available modeling techniques that will provide the required views. Even the available modeling techniques demanded a lot of efforts to be mastered to develop accurate models that will achieve its intended use and benefits. Moreover, the integration of these views was not straight forward; it required a lot of manipulations and thoughts.

The integrated multi-view was very complicated and confusing, that triggered the conclusion that it will be impractical to deliver it to the user in this format. Also, it was concluded that a computer based tool loaded with the knowledge from the integrated views with a highly usable graphical user interface will isolate the user from the complexity of the integrated views.

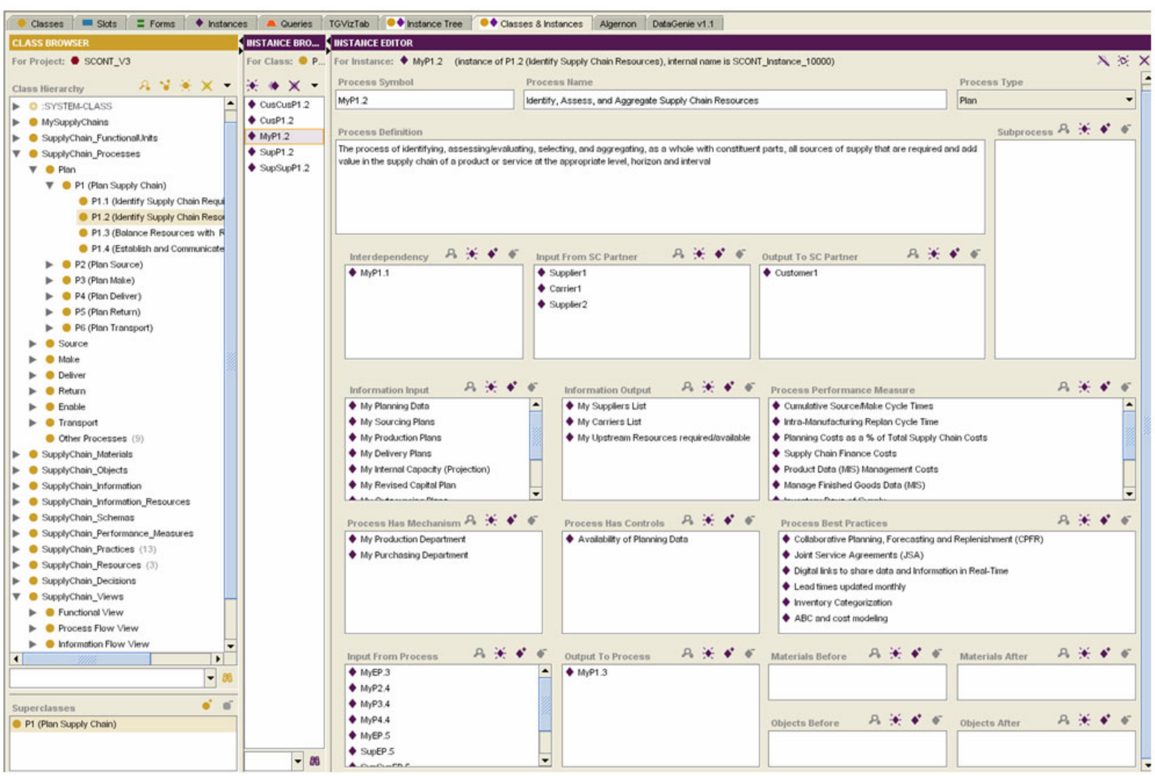

Figure 3: A Snapshot of the Process Element User Interface

At the same time the user interface will enable the user to derive a comprehensive definition of the supply chain utilizing the knowledge from the integrated views. In fact, Ontology is a successful approach to capture and model in a comprehensive way the knowledge of a particular domain. It also allows the knowledge to be reused, shared, and enriched with more knowledge using templates and automated procedures. However, developing the ontology required mastering an ontology language and an ontology development environment. It also demanded a great deal of effort to render a well structured, extensible, scalable ontology at the same time modular and constructed from generic reusable components. The development of the methodology embedded in an ontology based tool is very practical and feasible. However, the development of any ontology is iterative and requires a lot of time and effort to accomplish successfully.

The ontology will enable capturing the required distributed knowledge to build simulation models.

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